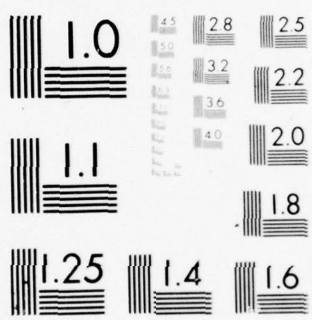
AD-A049 941 NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF F/G 9/2
PERSONAL COMPUTING. (U)
SEP 77 H P LIBUDA

UNCLASSIFIED NL

1 OF 1
AD
A049941

END
DATE
FILMED
4-78
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A049941

AD No. ____
DDC FILE COPY

NAVAL POSTGRADUATE SCHOOL
Monterey, California

D D C
RECEIVED
FEB 15 1978
REGISTER
A

THESIS

PERSONAL COMPUTING

by

Henry Paul Libuda

September 1977

Thesis Advisor: N. F. Schneidewind

Approved for public release; distribution unlimited

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 PERSONAL COMPUTING.		5. TYPE OF REPORT & PERIOD COVERED 9 Master's Thesis, September 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Henry Paul Libuda		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE 11 September 1977
		13. NUMBER OF PAGES 78 12 79p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The advent of the LSI microprocessor and inexpensive memory introduces a new field in the computer industry -- the field of personal computer applications and small scale computer systems. An entirely new group of manufacturers are marketing microcomputer related items, products that range from computer system kits with peripheral devices to software and literature on the subject. The wide ranging versatility of small scale microcomputer systems

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 450 JOB

(cont fr p1473A)

has caused a tremendous expansion from what was strictly a hobbyist computer market to growth areas in school educational markets and commercial applications. The costs, capabilities, problems encountered by personal computer enthusiasts, and the future implications of personal computers are investigated.

ACCESSION for
NTIS White Section
DDC Buff Section
UNANNOUNCED
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

Approved for public release; distribution unlimited

PERSONAL COMPUTING

by

Henry Paul Libuda
Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1971

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS SYSTEMS MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL

September 1977

Author: Henry Paul Libuda

Approved by: Norman Schneidewind
Thesis Advisor

Ronald J Roland
Second Reader

Chairman, Department of Administrative Sciences

Dean of Information and Policy Sciences

ABSTRACT

The advent of the LSI microprocessor and inexpensive memory introduces a new field in the computer industry - the field of personal computer applications and small scale computer systems. An entirely new group of manufacturers are marketing microcomputer related items, products that range from computer system kits with peripheral devices to software and literature on the subject. The wide ranging versatility of small scale microcomputer systems has caused a tremendous expansion from what was strictly a hobbyist computer market to growth areas in school educational markets and commercial applications. The costs, capabilities, problems encountered by personal computer enthusiasts, and the future implications of personal computers are investigated.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

The microprocessor is one of the most exciting innovations in the digital electronics field since the development of the transistor. Microprocessors are in fact revolutionizing digital electronics. Their impact is very similar to that which the transistor had on vacuum tube technology.

A microprocessor can be defined as a central processing unit (CPU) implemented in one or several integrated circuit (IC) packages. A microprocessor has the capability to fetch instructions from memory and decode them, accept data from internal memory or outside sources, perform arithmetic or logical operations and save the results in memory or send them to external displays or other devices [1]. A microprocessor can perform many of the functions of large central processing units.

The microprocessor is an outgrowth of large scale integration (LSI) in metal-oxide semiconductor (MOS) technology, a device fabrication process which allows complex electronic circuits to be placed on a single chip of silicon. By applying LSI techniques and MOS technology, manufacturers have been able to place the equivalent of 10,000 transistors on a chip of silicon less than a quarter of an inch square [2]. The production costs of complex chips is not significantly different from that of less

complex chips. The more circuitry that can be placed on a single chip, the cheaper the overall system costs will be. Such a single chip system requires fewer packages and connections, less power, less labor, and a smaller amount of supporting circuitry and equipment. LSI results in lower total cost if the same LSI device can be adapted to many different applications. Using these techniques, microprocessors have been built on one or just a few chips for costs in the range of $10 to $100.

When a microprocessor is combined with memory and input/output (I/O) devices, a microcomputer is formed with capabilities allowing it to replace circuitry implemented with conventional random logic (Boolean logic expressions implemented by the use of gating circuits) [3]. These microcomputers are not only finding use in small systems, where they may replace minicomputers, but they are also opening vast new areas of applications such as in personal/hobby computing where larger machines are not economically feasible. Prior to the development of the microprocessor, personal computing had been largely limited to the privileged few with access (authorized or not) to the computer facilities of their employers or the computers in their schools, colleges and universities. Few computer enthusiasts could either afford to buy their own minicomputer or were resourceful enough to construct their own equipment.

This picture is rapidly changing. The age of the affordable personal computer has arrived for many and will soon be here for many more - all because of the low priced microprocessor. The introduction of the MITS (Micro Instruments and Telemetry Systems) Altair computer kit in January of 1975 for an original cost of less than $400 demonstrated that almost anyone could now afford to own a computer [4].

Within six months of the introduction of the MITS Altair computer kit, other manufacturers, recognizing the market potential, began announcing compatible memory boards, interface boards, and peripheral devices. In the past two years, 250 - 300 retail computer stores catering specifically to computer hobbyists have come into existence. At present, over 180 computer clubs are in operation in Australia, New Zealand, Japan, and Canada as well as the U.S. Commercial periodicals published on a monthly basis and dedicated to the computer hobbyist have also appeared. Personal computing conventions have attracted voluminous crowds. Market surveys indicate that the market would expand from the 7500 personal computers in January of 1976 to over 18,000 such units by January of 1977 with a 250 per cent growth rate expected for 1977. Starting from zero in January of 1975, when it introduced the industry's first computer kit, MITS expects sales to exceed $12 million this year. In short, the personal/hobby computer market as it is emerging, is a sizable one [5].

B. GOALS OF THIS STUDY

The purpose of this study is to investigate the personal/hobby computer market. A history of that market is provided for perspective. It includes the background and development of microcomputers and personal computing. The technologies used and the architecture of microprocessors and microcomputers is covered in order to present their capabilities and limitations. In the course of describing personal computer system components, the following items are covered:

- ccst considerations
- support circuitry and requirements
  - clock circuitry
  - power supplies
  - memory
  - power of instruction set
- support from supplier
  - hardware support
    - mechanical hardware
    - processor cards
    - interface cards
    - documentation
  - software support
    - assemblers, compilers, interpreters
    - high level languages
    - utility programs
- literature
  - technical manuals
  - software manuals
  - application notes
- performance
  - speed
  - utilization
- interfacing
  - I/O flexibility and capability

Finally, the implications and future of personal computing is discussed.

II. HISTORY OF PERSONAL COMPUTING MARKET

A. PERSONAL COMPUTER INTEREST GROUPS

Potential home computer hobbyists received their first exposure to computers in the 1960's. Two of the most significant events during this period were (1) colleges installed timesharing terminals and instituted courses in BASIC and FORTRAN programming and (2) Texas Instruments Inc. introduced a series of integrated logic circuits (7400 TTL series) priced within range of amateur electronics experimenters. As a result, two distinct groups appeared: one, primarily software-oriented and another, hardware-oriented. The hardware group was characterized by the amateur electronics hobbyists, who used 7400 TTL series logic circuits for simple counting and control applications. Amateur electronics publications during this period invariably carried projects, utilizing 7400 TTL series logic, which helped stimulate interest in this area. The 7400 series integrated circuits were to convert a generation of "circuit designers" into a generation of "logic designers". Software-oriented people banded together into computer clubs, mostly to share BASIC programs [6, 7].

Typical of the computer clubs was The Amateur Computer Society organized in 1966 by like minded experimenters. They succeeded in constructing rudimentary TTL computers using scrap transistor logic boards and surplus core memory planes. Programming required expertise in machine or assembly language. Between the parts scrounging, debugging,

and the interfacing problems, only the skilled enthusiast made much progress. Though computer costs dropped rapidly throughout the 1960's, no hobby computer market developed during this time period, mainly because system-level hardware costs were still well beyond reach of most amateurs. For example, Digital Equipment Corporation's first minicomputer, the PDP-5, was introduced in 1963 for $30,000. In 1965, DEC introduced its popular 12-bit machine, the PDP-8, for what was then considered the incredibly low price of $18,000. By 1970, a basic PDP-8 configuration with 4K words of core was base priced at about $10,000, but this price was still above the range of the average amateur computerist [8].

Even if mini-computers had been affordable to amateur computerists, no sizable market would have developed since hardware-oriented and software-oriented factions still existed. Most software types were familiar only with interpretive languages. Those with some assembly-level knowledge rarely knew anything about interfacing hardware. Hardware types, slightly better off, had little or no experience with system-level software and generally worked at the digital logic level.

B. DEVELOPMENT OF MICROPROCESSORS

Manufacturers needed to create a base common to the hardware and software-oriented people for the hobby market to consolidate. This consolidation came in 1971, when Intel Corporation introduced the first microprocessor, the 4004. Intel had pioneered in the development of semiconductor memory chips to be used in large computers. In the intricate logic within memory chips, Intel design engineers knew it was possible to store a program to run a miniscule

computing circuit. In the course of a contract to produce a series of eleven chips for the logic circuits of a calculator, Intel condensed the layout onto three chips. The computer's brain, the central processing unit, consisted of one chip. This CPU on a chip of size less than one-sixth of an inch long and one-eighth of an inch wide came to be known as the 4004 microprocessor. Two memory chips were attached to this microprocessor, one to move data in and out of the CPU and one to provide the software program or instructions to drive the CPU. Intel now had a rudimentary general purpose computer known as the MCS-4 that could run a complex calculator, control an elevator or a set of traffic lights, and perform many other tasks, depending on its program [9]. The microcomputer was slower than minicomputers but it could be mass produced as a component, on the same high volume lines where Intel made memory chips - a surprising development that suddenly put the semiconductor business into the computer business.

Initially the semiconductor industry showed surprisingly little interest in Intel's technological advances. The big semiconductor companies - Texas Instruments, Motorola, and Fairchild - were preoccupied with their large current business, integrated circuits and calculator chips. Only Rockwell International and National Semiconductor entered the field early, about a year after Intel. To encourage adoption of microcomputers, Intel attempted to recast the thinking of industrial-design engineers by presenting microcomputer concepts through the use of a marketing and educational aid which developed into the Intel MICROMAP System. The message became clear that a microprocessor and its memory could replace a lot of individual logic chips. Hard wired logic systems could now be replaced with microcomputers because they could store program sequences in the memory chip instead of using separate logic chips and

discrete components to implement the desired function. A single microprocessor chip could be used for several thousand different applications by program code words substituting for hardware parts [3].

As industrial-design engineers started ordering microprocessors in large quantity, other companies rushed to establish a foothold in the microprocessor market. Their entry into the microprocessor line was achieved by "second sourcing" - i.e. copying - Intel's microcomputers. Second sourcing is a common practice in the semiconductor industry. More often than not, it is done without the original manufacturer's permission or cooperation, but the practice is widely accepted by the companies involved. It works to the benefit of the user in establishing a competitive source for the component as well as a backup source for the original manufacturer.

In 1972 Intel followed up the four-bit 4004 with an eight-bit microprocessor chip, the 8008, that had more computing power and flexibility than the 4004 and was more suitable for control applications and data handling. Toward the end of 1973 Intel brought out its second-generation microprocessor, the 8080. The 8080 had many improvements over its predecessor, the 8008. These improvements included additional instructions, a tenfold improvement in speed with a basic cycle time of 2 microseconds, and separate address and data buses. Most of the external logic supporting the 8008 was incorporated in the design of the 8080 CPU [9].

C. EMERGENCE OF PRESENT MARKET

By mid 1974, the hobby computer market was beginning to benefit from the microprocessor developments. Prior to mid 1974, the price of microprocessors was in the hundreds of dollars category for single units while the general availability of single units was limited. With the introduction of newly designed microprocessors in 1974, most notable of which being Motorola Corporation's M6800, competition within the microprocessor industry increased as did production efficiency and prices began to decrease. The cost of the Intel 8008 dipped below $100. New inroads were being made for the software-oriented group with BASIC interpreters being implemented on microcomputers and listings of tested BASIC programs for recreational use appearing in the literature [6].

The potential for a hobbyist computer market was clearly building among both the hardware-oriented and the software-oriented groups. MITS recognized this potential. Prior to 1974, MITS had developed several products for radio telemetry and offered a hand calculator in kit form for the consumer market. When mass production reduced profit margins within the calculator market, MITS began production of an inexpensive computer in kit form utilizing the Intel 8080 microprocessor. This computer, known as the MITS Altair 8800, was featured as the cover article of the January 1975 issue of Popular Electronics [4, 6]. MITS had hoped to sell 200 - 300 kits in 1975, but as it turned out, their projection was an order of magnitude too low. MITS realized that they had underestimated the market for a low cost ready to run microcomputer as they were deluged with orders for their $395 kits. The appeal of the kits was not

merely that they were affordable, but rather that they were understandable to hardware and software types alike. Aware that potential competitors had noticed the response tc the Altair 8800, MITS committed their efforts to gain and maintain a strong foothold in the personal computer market.

What had been an emerging market in the first half of 1975 became a developed market by the second half. MITS faced competition from firms that were able to capitalize on and improve the weaker features of the design which MITS had hurried to market. Among the early competitors were IMS Associates Inc. (IMSAI), Southwest Technical Products Corp. (SWTPC), Processor Technology Corp., and The Digital Group. Cost and product quality became competitive points as the new systems were introduced. Several of the newer systems were designed to be bus and printed circuit card compatible with the Altair 8800. The cross-compatibility amounted to a de facto standard, allowing smaller firms capable of producing memory boards and peripheral devices to become established in the personal computer industry [6].

Currently there are over 50 manufacturers producing microcomputer related products for the personal computer market. The wide ranging capabilities of their products is in part based on the characteristics of the microprocessors used in their systems. The types of microprocessors, technologies used to fabricate them, and their desirable features are discussed in order to present their capabilities.

III. MICROPROCESSOR CHARACTERISTICS

A. SEMICONDUCTOR TECHNOLOGIES

Microprocessors are manufactured using a variety of different semiconductor technologies. Most characteristics of interest in microprocessors are controlled by fabrication methods and an awareness of the performance of each technology will put the competing products in perspective. The importance of particular features as well as technological trends that may be of significance to hobbyists are described.

1. Desirable Characteristics

Some desirable characteristics include [10]:

Low cost: When devices from a particular technology can be produced cheaply, the ultimate cost will be lower. Cost is a function of the complexity of the semiconductor processes and of the amount of experience that has been acquired with a particular process. Semiconductor prices vary widely and the list prices established by manufacturers often don't closely follow the actual prices charged by distributors or electronic equipment supply houses.

High Density: When more complex circuits can be placed on a single chip, fewer devices will be needed to perform useful functions. More complex chips are not much

more expensive to manufacture, but require fewer packages, fewer connections, less board space, less external support logic, and less power than a larger number of chips. As higher circuit densities are achieved, the cost per function implemented on a chip decreases, resulting in lower cost for the memories and support circuitry.

Low power consumption: If the circuits produced from a particular technology require less power, they will require smaller power supplies, use less energy, and produce less heat. Devices that use large amounts of power require expensive power supplies and special cooling mechanisms such as fans.

Ruggedness: If devices made from a particular technology are more rugged, they will be able to withstand temperature variations, moisture, power surges, and shock which are likely to be present in the personal computer environment.

High speed: Devices that run faster can perform more work in a given time. Trade offs between the above characteristics and speed exist. Technologies that result in high speed typically are of low density and high cost.

Compatibility with standard TTL (Transistor - Transistor Logic) circuitry: If devices from a particular technology can be readily used with the standard 7400 series TTL integrated circuits, they can then be easily and cheaply interfaced to peripheral devices and other circuitry.

Wide availability and support: Devices of the same technology that are produced by many suppliers and heavily supported have more compatible parts available and lower prices.

2. Technology Related Characteristics

Microprocessors are currently available in six different technologies:

PMOS (P-Channel Metal Oxide Semiconductor): This is the oldest MOS technology. PMOS advantages include high density and low cost but it has relatively low speed and is not TTL compatible. Devices using PMOS generally require 3 distinct power supply voltages [11].

NMOS (N-Channel Metal Oxide Semiconductor): This is the present state of the art MOS technology. NMOS advantages include high density, moderate cost, and speed. NMOS devices can be made TTL compatible. Devices fabricated using NMOS techniques are more amenable than PMOS devices to working with a single power supply voltage [11].

CMOS (Complementary Metal Oxide Semiconductor): CMOS technology is widely used when low power consumption and high noise immunity are required. CMOS devices can be made TTL compatible and have medium density, cost and speed [11].

Schottky TTL (Schottky Transistor-Transistor Logic): This is a variation of standard TTL that offers a high speed, but these devices have a high power consumption and high cost along with a low density. Schottky TTL devices are fully compatible with standard TTL [12].

ECL (Emitter-Coupled Logic): This technology achieves very fast speeds but it is very expensive and consumes a large amount of power. ECL devices are not compatible with TTL [12].

I^2L (Integrated-Injection Logic): This new technology uses the standard TTL fabrication process, but yields circuitry that is as dense as MOS, as fast as TTL and yet consumes only 1/100 the power of TTL. I^2L allows special interface circuitry - digital and/or linear - on the same chip. This ability is important in many applications in minimizing costs through the elimination of peripheral parts which may be needed to support a MOS part to make it system compatible [13].

A comparison of these technologies is shown in Table 1. Clearly, PMOS and NMOS rank highest in the important categories of cost and density, CMOS ranks highest in ruggedness and lowest in power consumption, ECL is the fastest, while Schottky TTL is the easiest to interface [14].

At the present time, NMOS seems to have the most desirable combination of characteristics. It is relatively cheap, very dense, consumes little power, can be made compatible with standard TTL circuitry, and has a large family of compatible memories. NMOS can be used to make single-chip microprocessors which run at reasonable speeds. Such commonly used microprocessors as the Intel 8080, MOS Technology 6502, and Fairchild F-8 are made from the NMOS process. Most of the microcomputers manufactured for the hobby market employ NMOS microprocessors.

New developments in the NMOS technology could lead to considerable improvements. NMOS memories, such as the Intel 2115, are now available that are as fast as memories made from Schottky TTL. New NMOS processes have been introduced that can be easily interfaced with standard TTL circuitry and can use standard TTL power supplies [15].

TABLE ONE

Comparison of Semiconductor Technologies

	PMOS	NMOS	CMOS	Schottky TTL	I^2L	ECL
Cost (1=Lowest)	1	2	4	3	5	6
Density (1=Most Dense)	2	1	3	5	4	6
Power Consumption (1=Least)	3	4	1	5	2	6
Speed (1=Fastest)	6	5	4	2	3	1
TTL Compatibility	No	Sometimes	Sometimes	Yes	Yes	No
Ruggedness (1=Most Rugged)	5	4	1	3	2	6
Availability and Support (1=Most)	4	3	2	1	6	5
Standard Parts and Memories (1=Most)	4	3	2	1	6	5

Ref (14)

B. CATEGORIES OF MICROPROCESSORS

Currently, microprocessors can be divided into three basic categories:

1. Calculator-like processors,

2. Bit-sliced processors and others with a user-defined instruction set, and

3. Standard, self-contained processors with a fixed instruction set.

These three categories include a wide range of computing power, speed, price and application areas. Category 3 contains all of the microprocessors used in hobby computers, therefore the attention of this section will be focused on Category 3 while Categories 1 and 2 will be briefly described.

1. Calculator Like Processors

Category 1, the calculator-like processors, contains the simplest and cheapest devices. Typical processors in this category are the Intel 4004 and 4040, Rockwell PPS-4, Texas Instruments TMS-1000, American Microsystems 9209, and National Semiconductor IMP-4. Many of these devices are much like calculators; they are often specially designed or have special instructions to handle keyboards and lighted displays and to perform simple decimal arithmetic. However, these microprocessors are user-programmable and can be used in a wide variety of applications. Besides advanced

calculators, such devices have been used in character printers, games, household appliances, paper tape readers, test sets, function generators, counters, microfilm readers, telephones, tuners, valves, scales, cash registers, and time and attendance terminals [16, 17].

The devices of category 1 represent the smallest amount of computing power that can be purchased as a single unit. Complete systems based on these devices cost only $5 to $30 in large quantities. They are used mainly in applications requiring low cost, low speed, and relatively limited processing power. Such microprocessors are most often found in large volume applications as simple controllers for systems whose speed is limited by human interaction or slow mechanical devices. These processors generally have very short word lengths (most can handle 4 bits at a time) and are thus unsuited to systems requiring complex calculations, high data rates, or great accuracy.

Due to the rapid advancement of LSI technology, the difference in cost of manufacturing an 8-bit CPU chip as compared to a 4-bit chip is not significant. Manufacturers have attempted to prolong the life of their 4-bit products by maintaining an artificial price difference between their 4-bit and their 8-bit CPUs. As the pressure of competition continues, these price differentials are disappearing. Given this situation most users would prefer using an 8-bit microprocessor. Although 4-bit microprocessors are less used than in the past, they will continue to have a significant market for many years to come, based on products that were designed around them prior to the development of 8-bit microprocessors [16].

2. Bit Sliced Processors

The bit-sliced processors of Category 2 are largely intended as building blocks for special purpose computing elements. Unlike the devices in Categories 1 and 3, the bit-sliced processors are not self-contained. Although the concept of putting an entire microprocessor on a single chip is an attractive idea, the system consisting of several chips, each with a smaller number of components, can have its advantages: higher production yields, fewer connection pins per device, and better heat dissipation characteristics. Some multichip systems have the advantage that they can be microprogrammed by the user. The approach most often taken by manufacturers of bit-slice systems is to design one common control section and several two- or four-bit "slices" for the arithmetic and logic unit and the registers. The slices are connected in parallel, making it possible to assemble machines that have several different word lengths. These microprocessors are thus intermediate between the self-contained CPUs and the discrete circuitry that is currently used to make larger computers [18].

Most of the bit-sliced processors are much faster than standard microprocessors, but significantly more expensive and harder to use. CPUs based on these microprocessors typically cost $500 to $1500. Typical applications include disk controllers, minicomputer CPUs, test equipment, intelligent terminals, and signal processing equipment. The future may see bit-sliced processors as the basis for most minicomputers. Before these devices can be used in hobby computers, the cost and the number of elements required for a CPU will have to be significantly reduced [19].

3. Standard, Self-Contained Processors

The main category of microprocessors with which hobbyists are presently concerned is Category 3, the standard, self-contained processors with a fixed instruction set. These processors are intermediate in performance between calculators and minicomputers (i.e., between categories 1 and 2). They are complete CPUs on one or a few chips and require only a small amount of supporting circuitry. Prices for these devices range from $20 to $200 in single quantities (not including memory, I/O, or other system requirements). Most of the devices of Category 3 will handle 8 bits of information, although a few can handle 16 bits at once. The most widely used microprocessors among hobbyists are:

Intel 8080

The Intel 8080 was the first device in this category to be introduced and is the most widely used in hobby computers; as such, it has become the frame of reference in many people's minds as to what a microprocessor should be. The 8080 consists of an arithmetic and logic unit, control unit, accumulator and registers and is fabricated using NMOS technology. The 8080 requires separate clock logic and bus interface logic. These features are provided by the use of external logic chips in the 8080 family [20].

Included in the 8080 family are the following devices [21]:

- 8224 System Clock Generator and Driver. This device generates a 500 nanosecond timing signal for the entire 8080 microcomputer system. Instruction execution times range from 2 to 9 microseconds.

- 8228 System Controller. This device demultiplexes the data lines of the 8080 CPU which are used for bidirectional data transfer and to output control and status symbols.

- 8251 Serial I/O Communication Interface which provides a variety of synchronous and asynchronous serial data communications options.

- 8255 Parallel I/O Interface which provides programmable I/O communication with external devices.

- 8212 I/O port, which can be used as an address buffer/decoder, a priority interrupt arbitrator, or an I/O peripheral interface.

- 8257 Direct Memory Access control device, which enables data to be transferred between memory and external logic, bypassing the CPU.

All devices in the 8080 family have TTL compatible signals and require three levels of power supply: +5V, +12V and -5V. The 8080 has a set of 78 instructions. The 8080 is used in the MITS Altair 8800, IMSAI 8080, and in similar sets from The Digital Group and other sources.

Zilog Z-80

The Zilog Z-80, an NMOS device, is often referred to as a "third generation" microprocessor. The Z-80 was designed by the same individuals responsible for designing the 8080 at Intel and is an extended version of the Intel 8080. The Z-80 microprocessor implements the functions of three devices of the 8080 family: 8080 CPU, 8224 Clock and 8228 System Controller [22]. For the programmer, the Z-80 provides more registers and addressing modes than the 8080, plus a set of 158 instructions that include the 78 instructions of the 8080 as a subset. Compatibility between these microprocessors is limited to the instruction sets and general functional capabilities. Within certain limits, programs written for an 8080 microcomputer system are

software compatible with a Z-80 based system. For example, a ROM device that is used to implement object programs for an 8080 microcomputer system can be physically removed and used in a Z-80 system [23]. Support devices that have been designed for an 8080 CPU will also support a Z-80 system, allowing an upgrade of an 8080 system to Z-80 capabilities by replacement of the microprocessor and additional interfacing logic [24].

With a standard clock speed of 400 nanoseconds, instruction execution time is 1.6 microseconds. The Z-80 requires a single power supply voltage (+5V).

Microcomputers utilizing the Z-80 microprocessor are available from The Digital Group and Cromenco. The Z-80 is available as a replacement CPU card from Affordable Computer Products and Technical Design Labs.

Motorola 6800

The Motorola 6800 is comparable to the Intel 8080 in performance. It is the second most widely used microprocessor in personal computing systems following the 8080. Like the 8080 and Z-80, the Motorola 6800 is an 8-bit NMOS microprocessor which is TTL compatible. The M6800 was designed by Motorola as an enhancement of the Intel 8008, at the same time that Intel was developing the 8080 as an enhancement of the 8008.

As compared with the 8080, the M6800 has a less complex set of control signals and does not require any device equivalent to the 8228 System Controller. Whereas the 8080 has separate I/O instructions, the M6800 includes memory and I/O within a single address space allowing all I/O device accessing as memory locations. While the 8080 requires three power supply voltages, the M6800 uses just one (+5V). The instruction set of the M6800 has fewer basic

instruction types with more memory addressing options while the 8080 has a larger number of special instructions [25,26].

The M6800 is used in the MITS Altair 680 and other hobby sets from SouthWest Technical Products Company (SWTPC), Sphere, Wave Mate, and Ohio Scientific Instruments.

MOS Technology 6502

The MOS Technology 6502 is also comparable to the Intel 8080 and Motorola 6800 in terms of performance. It was first introduced in 1975 and is used in the JOLT hobby computer and others. The MOS Technology 6502 is somewhat cheaper than either the Intel 8080 or Motorola 6800, but not as widely used [19].

National PACE

The National PACE has a slower instruction execution speed than any of the previously mentioned processors and is somewhat more expensive. It will, however, handle 16 bits of information at a time (the others handle 8 bits) and has a more powerful instruction set [27]. Systems based on this processor are available from Godbout Electronics and from Hamilton-Avnet (the Pacer).

Intersil 6100

The Intersil 6100 is more recent than the above microprocessors. It can execute all the instructions of the PDP-8 minicomputer. The advantage of the Intersil processor is that programs available for the PDP-8 can be used on systems based on the Intersil 6100 [28]. Systems based on this processor can be obtained from PCM Corporation or Ohio Scientific Instruments.

Other processors in category 3 which may eventually be used in hobby computers include the Rockwell PPS-8, Signetics 2650, RCA CDP 1802 (COSMAC), Fairchild F-8, and General Instrument CP-1600. The devices in category 3 are used in many applications besides hobby computers. Among the more common are monitoring systems, line printers, navigation systems, oscilloscopes, message switching units, and graphics terminals [29]. These microprocessors will probably continue to have the widest variety of applications in the near future.

C. MICROPROCESSOR SELECTION CONSIDERATIONS

A comparison of microprocessors is difficult because of the wide diversity of architectures and support circuitry of the available microprocessors. Since microprocessor-based systems must be programmed like conventional computers, software as well as hardware must be considered. The intricacies of either entails different tradeoffs between hardware and software. Microprocessor comparisons are not helped much by the expanding volume of application literature offered with "computers on a chip." Documentation often inflates or omits key specifications. Important characteristics, such as operating speed, are difficult to extrapolate from the voluminous data. Typical data sheets specify a basic cycle time and clock rate. Many microcomputer operations require several cycles to be performed, particularly in the case of the more powerful instructions which take more time than the basic cycle indicates. Similarly, it is possible for one microprocessor with a seemingly high clock rate to perform a fundamental operation - such as a register-to-register add - more slowly than it is performed with a slower clock[10].

Manufacturers' promotional materials often elevate a selling point, such as CPU cost, into an unwarranted selection factor. The cost of additional support components (peripheral and interfacing circuits, and memory) exceeds the prices of CPUs by a wide margin. The prices of computer kits vary widely, although they may use the same microprocessor and offer about the same features. Sometimes the difference in price is due to the use of less expensive ICs in the lower-priced models which have more constraining temperature and voltage limitations. While some manufacturers may stress that their chip sets can operate at one TTL level of 5 volts, more than a single power supply may be required if some of the newer memories are used.

A widely omitted specification is noise immunity. A comparison between levels for peripheral circuits and the address-output levels of the microprocessor may indicate little or no protection against unwanted transient waveforms. Noise immunity is of importance when a microcomputer is moved from a clean, noise-free bench into a personal computer environment. The newer microprocessors, such as the CMOS Intersil 6100, excel in this area, a strong point of the low-power CMOS technology [10]. Other hardware considerations are discussed in Section IV of this study.

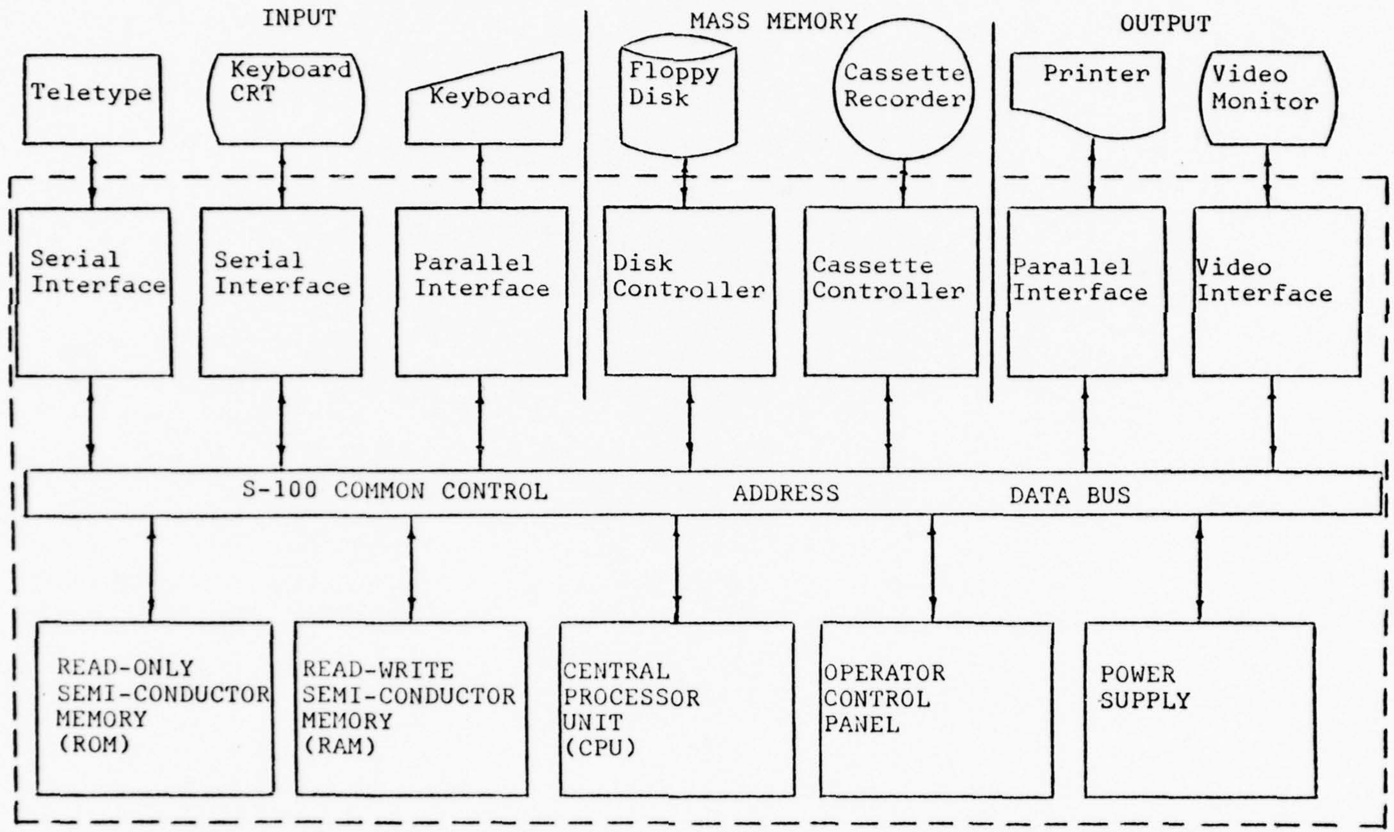
A microprocessor's instruction set and architecture determine one of the most frequently stressed selection factors - programming ease. Microprocessor-chip designers are constrained by limitations of technology and packaging size. As a result, each microprocessor reflects a different series of compromises and tradeoffs in implementing programming. Specific software considerations of importance to the personal computer user are discussed in Section V of this study.

IV. HARDWARE COMPONENTS OF PERSONAL COMPUTER SYSTEMS

At the time of its January 1975 introduction, the Altair 8800 was intended to fill the rising demand for a hobby computer. The Altair 8800 first appeared in kit form, aimed at the electronics kit builder market. In the two years since the introduction of the Altair 8800, more than 50 manufacturers have developed and are marketing their own versions of microcomputers. The market has changed from what was strictly a hobby market to what can now be better termed a small scale or personal computing market with applications of microcomputers in areas that include business and school education as well as hobby use. Today, systems are available in kit form requiring assembly of logic elements, as assembled components (much like a stereo system), or as completely integrated systems with all the necessary components sold as a unit for turnkey operation. The savings realized on unassembled kits ranges from 20 to 40 per cent of the cost of the assembled version. From the hardware standpoint, all of the present personal microcomputer systems bear similarities. Figure 1 depicts a typical microcomputer system. The blocks represent the various components and their interconnections.

FIGURE ONE

Microcomputer System Components



A. MICROCOMPUTER MAINFRAMES

The mainframes of the available personal computers are strikingly similar. The mainframes consist of a CPU card, memory card, power supply, and control panel, all of which are interconnected by a bus structure. The most commonly used bus structure in mainframes is the S-100 bus. Table 2 provides a comparison of several personal computer mainframe assemblies.

1. S-1C(Bus

The Standard-100 or S-100 control, address, and data bus has beccme a de facto standard in the micrccomputer industry. The S-100 bus, which consists of a bank of 100-contact connectors wired in parallel on a commcn mother board, was developed by MITS for their Altair 8800 microcomputer. The 100 lines of the bus carry address, data, and control signal information between the various components of the microcomputer system. The S-100 bus structure allows the microcomputer's CPU and memory to be mounted cn separate printed circuit (PC) cards and also provides space for additional PC cards for system expansion. Using PC cards with interfacing logic, peripheral devices such as floppy disk drives, CRTs, line printers, and cassette recorders, can be added to the system. Cards on the S-100 bus are often functionally independent and transparent to the operation of the other cards such that adding or deleting a card does not effect the operation of other system components. Additional memory or I/O interfaces are added by removing the mainframe cover and plugging in additional circuit cards. The S-100 bus

TABLE TWO

Personal Computer Mainframes

Manufacturer	Microprocessor Mfg.	Microprocessor Device	Standard Features Type Bus	Standard Features No. Slots	Standard Features Memory	Standard Features I/O Interface	Kit	Assembled	Comments
The Digital Group	Intel	8080	MB-1	4	2K RAM	T.V. Read-out & Audio Cassette	$425	$645	Software Optional
	Zilog	Z-80	MB-1	4	2K RAM	"	475	695	"
	Motorola	6800	MB-1	4	2K RAM	"	425	645	"
	MOS Tech	6502	MB-1	4	2K RAM	"	375	595	"
IMS Associates (IMSAI)	Intel	8080	S-100	22	-	-	599	931	I/O interfaces memory & software optional
MITS	Intel	8080	S-100	18	256 Byte RAM	-	569	859	"
	Motorola	6800	S-100	3	1K RAM	Serial I/O (TTY or RS232)	466	625	Includes 256 Byte PROM Monitor
SWTPC	Motorola	6800	SWTPC	6	2K RAM	"	395	-	Include PROM Monitor

structure allows microprocessors to be changed or upgraded by removing one card and inserting another in its place. This allows considerable versatility by permitting easy system upgrades to increased memory capacity and more powerful processors as the hobbyist requirements increase [31].

The widespread adoption of the S-100 bus structure has been a key reason for the rapid growth of the personal computer industry. Over 20,000 mainframes using the S-100 bus are presently in use. Other manufacturers have been able to supply compatible memory boards, interface boards and peripherals designed to S-100 specifications and thus provide support to the microcomputer mainframe manufacturer as well as further their own cause.

2. Power Supply

In order to keep the cost of the mainframe low, unregulated power supplies are normally used. The S-100 bus requires power supply voltages of +8 volts, +18 volts, and -18 volts to support the variety of memory and I/O interface cards that can be used with the system. The number of extra sockets available in the S-100 bus and the amperage rating of the power supply normally determines the number of peripheral device interface and memory boards that can be supported. As an option to most systems, the S-100 bus can be extended and additional power supplies added in order to support more peripherals. With system expansion in this manner, cooling equipment often becomes a necessity [32].

3. Memories

The memory within the microcomputer mainframe may be divided into two broad classes, read-only memory (ROM) and read-write memory (RAM). The ROM supplied with most microcomputer systems is contained on the CPU card while the RAM usually comprises a separate card. Because RAM requires additional circuitry to implement the write function, RAM is typically less dense than ROM on PC boards. The amount of memory provided with the mainframe by microcomputer manufacturers varies widely and depends in part on the units' intended application. Generally, the minimum amounts of read-write memory and read-only memory provided are 512 bytes and 1K bytes respectively. Expansion of RAM and ROM to a combined total capacity of about 64K is usually possible and is left as an option to the buyer [32].

a. ROM

Read-only memory forms an important part of the memory requirement in most microcomputer systems. Instructions, the coded pieces of information that direct the activities of the CPU are stored in read-only memory, which, as its name implies, may be read but not altered under program control. ROM, being a fixed memory, is non-volatile; i.e., a loss of power or a malfunction to the system does not change the contents of the ROM. Most ROMs have the feature of random access such that memory access time is independent of the memory location being accessed [33].

ROMs are often employed in personal computers for bootstrap loading whereby a built-in ROM contains enough

permanently stored information (firmware) to allow the computer to accept a new program as soon as the power is turned on. Key systems programs (monitors and interpreters) are sometimes provided by microcomputer manufacturers in ROM form to eliminate the necessity of having to read them into memory every time the computer is turned on. The MIKBUG ROM operating system used with Motorola M6800 processor based systems is an example of such a monitor [34]. ROMs are also employed in microcomputer systems that are dedicated to a single application such as a process controller.

ROMs that are programmable are referred to as PROMs and exist in several forms. The programmming technique used to store information into the ROM can be used to classify all ROMs into one of three categories [35]. The first category consists of ROMs that are custom or masked programmed during manufacturing and cannot be changed after fabrication. This type of Programmed ROM has been employed to supply microcomputer systems with BASIC language interpreter capability and assembler/resident operating systems. Cromenco Inc. distributes such an interpreter, 3K BASIC, implemented on 3 PROM devices at a cost of $150. Cromenco Inc. also distributes an assembler and resident operating system implemented on 8 PROMs, available at a cost of $400. The second category includes ROMs which are user programmable by modification of fusible links. These Programmable ROMs (PROMs), once programmed, have permanently fixed contents. The third category of ROM is reprogrammable using electrical or optical means. The contents of these electrically programmable ROMs (EPROMs) can be altered again and again.

PROMs are finding use in personal computers as a convenient storage place to transfer the program contents from the microcomputer's volatile read/write memory when the power is turned off. Using the software provided with

systems such as the Cromenco BYTESAVER that employ PROMs in this manner, frequently used programs may be transferred from non-permanent RAM to the permanent PROM [36]. Once the program is stored in PROM, it is protected from power turn-offs, either accidental or intentional.

b. RAM

General-purpose microcomputers of interest to the computer hobbyist require read/write memories for both programs and data. Even though ROMs are technically random-access memory (RAM) elements, the read/write memory, which is an array of active, volatile elements, is frequently referred to as RAM. RAM is the direct functional equivalent of the core memories that have been the mainstay of computer storage for two decades.

RAMs exist in two classes, static and dynamic. Static RAMs store each bit of information in a flip-flop which retains this information as long as power is supplied to the circuit. Dynamic RAMs store information in the form of electric charge on the gate-to-substrate capacitance of a MOS transistor. This electric charge dissipates in a few milliseconds unless a periodic "refresh" is applied. Dynamic RAMs are faster than static RAMs and consume less power in the quiescent state but the refreshing cycle requires additional circuitry. Unlike ROMs, RAMs are volatile and lose their contents when power is turned off. Because of the volatile nature of RAMs, high speed input devices for loading memory are desirable in hobby computer systems [37].

Most personal computer systems are designed to accept additional memory circuit boards to expand memory. The amount of RAM memory required varies with the system's

software requirements. When assembler software and high level language interpreter programs are not implemented on ROM devices, RAM memory is required for these purposes. Typical assembler programs require 8K bytes of storage while high level language interpreters require from 4K to 16K bytes of storage. Additional RAM is required for the user's application program. The cost of providing this memory can dominate the system cost. Personal computer systems incorporating memory bank select capabilities can expand memory up to a half megabyte. However each 4 kilobyte RAM memory section can cost up to $200 [32].

Cassette tape recorders have provided an answer to the requirement for low cost mass storage. Mass storage devices are discussed in a following section on peripheral devices.

4. Central Processing Unit

The remaining component of the microcomputer mainframe is the microprocessor card which holds the CPU of the system. As previously stated, the functions of the CPU are to fetch instructions from memory, decode their binary contents, and execute them. The CPU also accesses memory and I/O ports as necessary in the execution of instructions and recognizes and responds to certain external control signals, such as Interrupt and Wait requests.

It is often difficult to make a comparison of the versatility and efficiency with which different microprocessors perform these operations. Instruction sets are very subjective and a comparison of the power of two different microprocessors made on the basis of the size of their instruction set or on the basis of implementation of a benchmark program can be misleading. Benchmark programs can

be a priori biased since they are written by programmers who can well be more familiar with the internal data manipulations and I/O operations of a particular microprocessor and thus more efficiently sequence the instructions of the benchmark program for that microprocessor [38].

From the viewpoint of the hobbyist or personal computer user, an evaluation of the different microprocessors should be made on the basis of the following:

- Functions to be performed
- Hardware requirements
- Time limitations
- Memory requirements
- Documentation available
- Programming language
- Software provided

The functions to be performed and the ability of the instruction set to implement these functions gives a clear view of the applicability of a particular microprocessor to the task. For example, although the Z-80 instruction set includes 80 more instructions than the 8080, a novice programmer may find the Z-80 instruction set to be bewilderingly complex. The 8080 instruction set may well satisfy the functions required by the novice while the additional instructions provided by a Z-80 microprocessor may remain unused. Similarly the ability of a microprocessor to be microprogrammed can be a needless feature. Although microprogramming provides the capability of tailoring the instruction set to the user's particular application, for many users, it simply introduces an additional complexity. In addition to microprogramming the machine, the user must generate his own software - a formidable task for the novice [39].

The amount of hardware governs the physical size and cost of a system. Hardware requirements for microcomputers are determined to a great extent by the input/output operations required. Systems based on one microprocessor may require fewer hardware interfaces than systems based on two microprocessors. However, systems that have a greater amount of hardware may have simpler software requirements. To evaluate this tradeoff in costs, a benchmark program can be beneficial.

Among personal computer users, instruction execution speed is perhaps the least consequential consideration. High system throughput is not as important a consideration as in large scale time-shared computer systems. To the hobbyist, price is crucial while speed and reliability are secondary.

Memory requirements differ between microprocessors because of differences in modes of memory addressing and I/O operations. Since the cost of providing read/write memory can be great, any means of decreasing this cost is of benefit to the hobbyist.

Other items to be considered during selection of a microprocessor include the availability of documentation for that microprocessor, the programming languages used, and the software provided by the vendor. Software support and programming languages are addressed in section V of this study.

B. PERIPHERAL DEVICES

A microcomputer mainframe with the basic components that allow it to be classified as a microcomputer can be acquired

at costs from $395 for a South West Technical Products Company 6800 in kit form to $995 for an assembled version of Cromenco's Z-1. As in the case of a CPU on a chip being advertised at a seemingly low price of $20, microcomputer mainframes are likewise advertised at what seem to be reasonable prices to the uninitiated. Without the supporting memory, I/O circuitry, and power supply, the CPU on a chip is a long way from being classified as a microcomputer. Likewise the microcomputer mainframe is a long way from being a working computer system. In order for the microcomputer mainframe to interact with the outside world, input and output devices (peripherals) are required. Peripherals include teletypewriters, paper tape readers and punches, CRT displays, keyboards, cassette tape recorders, floppy disk drives, and printers. Although personal computing enthusiasts are using some of the traditional computer peripherals, the relatively low cost ones, a variety of peripherals that are unique to the small scale computer market, are also available. In contrast to the peripherals used in large scale computer systems, personal computer peripherals are at the lower end of the performance scale. In this section, several peripherals available for use in personal computing and their interfacing requirements are described.

1. Interfacing Requirements

When one or more I/O devices are connected to a microcomputer, an interface network for each device, known as a peripheral interface is required. Peripheral interfaces are used to convert information that is being passed from the peripheral device to the computer into a format that is compatible with the computer. Likewise during a transfer of information from the computer to a peripheral device, the peripheral interface converts the

information into the required format for the peripheral. In order to reconcile any timing differences between the computer and a peripheral, the interface usually must supply status information to the computer (e.g., READY or BUSY) [20, 23].

Four features common to peripheral interfaces include buffering, address decoding or device selection, command decoding, and timing and control capabilities. The buffer capability is required to synchronize data exchanges between the CPU and the peripheral. The address decoding feature is necessary for selection of an I/O device in systems with multiple peripherals. Command decoding is provided in some systems for I/O devices that perform actions other than data transfers, such as control of a tape drive. Finally, each of these functions requires timing and control [40].

The interfacing requirements of a particular microcomputer system are determined by the characteristics of the peripheral devices employed in the system. Peripheral devices generate and accept data in either parallel or serial formats. Devices that employ parallel formats, such as keyboards, analog to digital (A/D) converters and digital to analog (D/A) converters, send or receive all the bits in a data word or keyboard character simultaneously. The interfaces for parallel format devices simply provide electrical compatibility and proper timing for transfers to and from the microprocessor or Direct Memory Access (DMA) bus.

In programmed data transfer operations, information to be placed in memory is transferred from the input device via the processor to the designated memory location. In a similar fashion, data that is to be output from memory goes by way of the processor. This type of data transfer ties up

the processor during the entire data transfer. In order to permit overlap of I/O and processor functions, some microprocessors have a hold provision that enables Direct Memory Access (DMA) operations. The DMA allows the peripheral device to transfer data directly [41].

In devices that use serial formats, a data word is sent or received one bit at a time. Since the microprocessor is a parallel word processor, the peripheral interface, in this case, must perform serial-to-parallel and parallel-to-serial transformations in exchanging data to and from the processor or DMA data bus. Serial interfaces are typically more expensive than parallel interfaces because of these data transformations.

The selection of the peripheral devices to be used on a personal computer system is important because in many instances, the cost of these devices exceeds that of the microcomputer mainframe components. Requirements by a microcomputer for interface logic can add significant cost to the total system [42]. These requirements vary from system to system dependent upon both what is initially supplied for interfacing in the mainframe and microprocessor capabilities. A tabulation of the available interface boards and their costs is given in Table 3. The cost of providing interface boards for a microcomputer system can be minimized by the use of boards designated as multiple I/O (MIO) boards which can handle the interface needs of more than one peripheral device. An example of an MIO board is the IMSAI MIO with five ports. This MIO board combines the most commonly used I/O interfaces on a single board with a control port, serial channel, cassette interface, and two parallel I/O ports. With this MIO board, a keyboard, printer, tape cassette and teletype (or CRT) can all be controlled simultaneously.

TABLE THREE

Standard Input/Output Interfaces

IMSAI Cat. No.	Description	Kit Price*	Assembled Price*
MIO	Multiple I/O Board (2 parallel, 1 serial, 1 cassette tape interface)	$195	$350
PIO 4-1	One port parallel I/O Board (Keyboard, A/D & D/A converters)	93	140
PIO 4-4	Four port parallel I/O Board (Alphanumeric Printer)	156	299
SIO 2-1	One channel serial I/O Board (Teletype, Keyboard CRT Terminal)	125	235
SIO 2-2	Two Channel serial I/O Board	156	299
PIO 6-6	Programmable 6-port parallel I/O Board (bidirectional data flow)	169	279
PIO 6-3	Programmable 3-port parallel I/O Board	139	239

*Ref IMS Associates January 1977 Price List

2. Hardcopy Devices

As personal computer use grows, so does the demand for low cost hardcopy output devices. Without hardcopy printout, debugging a long program can be difficult. Since line printers that utilize chain printer mechanisms are typically too costly to justify for use on personal computer systems, several alternate hardcopy output devices are employed. These hardcopy peripherals include teletypes, IBM Selectric keyboard printers, and dot matrix printers.

a. Teletypewriters

Many of Teletype Corporation's ASR-33 (automatic send-receive) teletypewriter sets are available on the surplus market. This device offers a keyboard which transmits 8-level ASCII code, a typing unit for producing hardcopy, a paper tape reader, and a paper punch. The ASR-33 is a low speed device which transmits or receives data at a maximum rate of 10 characters per second. The paper tape unit can be used to read paper tape programs which load monitors, assemblers, debug routines and high level software into the computer system.

ASR-33 teletypes are available on the surplus market in "as is" condition for as little as $250 but may require extensive parts replacement. ASR-33s that have been under regular maintenance contracts command a price of $350 - $400 while reconditioned units sell for $700 - $900. Although they are generally unavailable from terminal dealers who prefer to rent rather than sell the ASR-33s outright, new units can be acquired through hobby computer stores for a price of $1350 [43].

Because the ASR-33 employs a serial format for data transmission between the teletype and the computer, either an RS-232 voltage terminal or 20 ma TTY current loop interface board must be provided in the computer mainframe. Special integrated circuits such as the universal asynchronous receiver-transmitter (UART) are available for this purpose. The cost of this interface can add $40 to the total system cost if the computer mainframe does not have this provision built in [44].

b. IBM Selectric Keyboard Printer

One of the most desirable forms of computer output is high quality typewritten text suitable for preparing letters, reports, and other documentation. A word processing system which speeds up the process of writing and revising text would be a very useful and feasible application for a small microprocessor based system, provided that a suitable hard copy output device can be found at a reasonable price. The IBM Selectric Input/Output Keyboard Printer provides an ideal output medium for such a word processing system. Selectric I/O units have found their way into the surplus market as the IBM computer systems that they were designed for have become obsolete. Prices for these units range from $250 to $1500. Interfacing hardware and logic adds an additional $100 to this cost [45].

c. Matrix Impact Printers

As an alternative to teletype terminals which can be both costly and bulky, dot matrix printers are available for hardcopy output. An example of a printer of this type is the SWTPC PR-40 Alphanumeric Printer, available

in kit form for $250. It uses a 5 by 7 dot matrix to print 40 characters per line at a rate of 75 lines per minute on standard 3.875 inch rolls of adding machine paper. This printer requires no head positioning circuitry thereby simplifying the requirements placed on its driver electronics. One complete line is printed at a time from an internal 40 character first in first out buffer memory. Printing occurs either on receipt of a carriage control signal or automatically whenever the line buffer memory is filled. This printer is approximately the size of a cigar box and incorporates TTL compatibility [46].

3. CRT Displays

Cathode Ray Tube (CRT) displays provide a very effective medium for interactive use of personal computing systems. Although they have the disadvantage of being unable to provide hardcopy output, their low operation cost, silent operation and versatility make CRT displays desirable. CRT display units used in personal computing are divided into two categories: video terminals which include a keyboard, and modified television sets and video monitors without keyboards.

a. Video Terminals

The versatility of video terminals increases the value of personal computers as tools by enhancing the communication between the system and the user. The user supplies information through the keyboard input for processing by the system and the system displays the resulting data on the monitor screen in character or graphic form. Video terminals with the logic required to allow cursor control, character read at cursor position, scrolling

or paging operation modes, display of up to 48 lines with 80 characters per line, and expandable RAM memory for display storage are available to personal computer enthusiasts through both surplus equipment supply houses and as new units with prices ranging from $200 up to $1250. New units are normally supplied with the equipment necessary to interface with the microcomputer [47].

b. Television Typewriters

Although video terminals are desirable additions to personal computing systems, their high cost relative to the computer mainframe cost places video terminals beyond the reach of most hobbyists. The problem of providing a low cost video display has been solved by using the standard home television monitor as a TV typewriter. The logic required to interface the home television with the computer is available on S-100 bus PC cards designed for this purpose. Data to be displayed on the television is stored in a portion of the computer's RAM memory. A reading of the RAM produces the video signal used for creating the alphanumeric display. The video signal is then passed through a video-to-RF converter, attached to the antenna leads of the television. The video-to-RF conversion, required by FCC regulations, reduces the available bandwidth such that only 32 to 40 character positions per line are available. Home televisions adapted in this manner typically display 16 to 32 lines, and do not have the cursor and scrolling capabilities of the commercially available video terminals. However, the cost of converting the home television to this use is less than $100 and it still can be used for its traditional purpose [48].

c. Video Monitors

A variety of video monitors designed specifically for use as monitors, are available and have capabilities that are not available on a television set conversion. These monitors accept video output without conversion to RF which allows a wider video bandwidth for a larger number of lines and characters per line in the presentation. While video terminals provide a keyboard for data input, video monitors and television typewriters lack this feature.

4. Other Input/Output Devices

a. Paper Tape Readers

Most microcomputer manufacturers use paper tape as a media for distributing programs, updates, and diagnostics because of its low cost and ease of handling and mailing. As an alternative to the use of high priced teletype terminals to enter paper tape programs, several low cost ($75 price range) paper tape readers are available for personal computer systems. These devices have no moving parts and incorporate optical sensor arrays to read the perforations of the paper tapes. The reading speed of these devices is a function of the dexterity of the user who pulls the tape through the device. All the required handshake logic to interface with any microprocessor I/O port is included with the unit.

b. Keyboards

Although the front panel address and data switches, which are present on some personal computer main frame assemblies, can be used for entering basic monitor programs, more extensive programming in high level languages such as BASIC require the use of a keyboard input. Standard ASCII keyboards with positive control logic, control characters, and the necessary cables for interfacing the microcomputer are available in kit form for $125 or they can be procured assembled for $200. Keyboards require a 1 port parallel I/O interface board which adds $93 (kit) or $140 (assembled) to the price of this input device.

5. Mass Storage Devices

a. Audio Cassette Recorders

Magnetic cassette tapes are the most flexible and least expensive means of mass data storage for personal computer systems. The utility of cassette tape recorders lies in their ability to provide a high-speed (compared to keyboard or paper tape) input medium and a permanent storage for retaining long programs after they have been developed. Cassette tape also serves as an important medium for the exchange of programs. By using audio cassettes, a hobbyist can easily store long programs, such as a BASIC interpreter, and load them into computer RAM in less than 30 seconds.

An early standardization for computer data encoding on audio cassettes has benefited personal computing

by allowing the exchange of programs in machine readable form between those using the same standard. In order to exploit the most effective recording technique and to coordinate design efforts, BYTE magazine sponsored a symposium in the Fall of 1975 in Kansas City in an attempt to establish a recording standard for the storage of digital data on cassette recorders. The standard developed was to record data serially using UART format at 30 characters/second. Marks or logic ones are represented by recording a 2400 Hz sine wave on the tape while spaces or zeros are represented by recording a 1200 Hz sine wave. With the proper circuitry this recorded data can then be read off the tape into a self clocking UART based tape system which will tolerate audio recorder speed variations of approximately plus or minus 30 per cent. The 30 per cent tolerance allows speed variations due to line voltage, battery voltage, wow and flutter, and mechanism wear. However, this "Kansas City" standard did not specify how data was to be organized on the tape. This can lead to incompatibility among various manufacturer's units [49].

While the low price and widespread availability of audio cassette recorders makes these units attractive to personal computer users, the interface to perform the above frequency shift keying operations is expensive in comparison to the recorder costs. Southwest Technical Products Company offers such an interface in kit form for $80. It includes status indicators to show read and write states as well as valid data flow and provides manual or computer control over the cassette's operation in read/record modes [50].

b. Digital Cassette Recorders

Although there are several commercial digital cassette tape decks on the market today, recording

techniques vary and they are significantly more expensive than the average audio cassette unit. The digital cassette tape units that are on the market incorporate many features such as handshaking with terminals and modems and software control of start/stop. The cost of a digital data recorder manufactured by National Multiplex Corp., that can run at any baud rate up to 4800, is $175. To interface with the computer, an RS-232 voltage interface is required while the software control of start/stop also requires a separate interface board. This can increase the total cost of digital cassette recording by $100 [50].

c. Floppy Disk Drives

Flexible magnetic disc (floppy disk) systems provide random access capability to program/data storage. Hard-sector formatted, each disk holds over 300,000 data bytes. The floppy disc provides a much faster data transfer rate than cassette recordings but unfortunately the average $1200 cost of most floppy disk systems makes them too expensive for most hobbyists.

The recent development of a mini-floppy disk drive that provides random access mass storage at a cost that is well below that of a full size floppy disc may make the mini-floppy a standard for the personal computer industry. North Star Computers, Inc. has introduced a mini-floppy disk system that has a 90K data byte capacity for each disk. The $599 cost of this system includes PROM bootstrap, a file-oriented disk operating system, a 12K version of BASIC with sequential and random disk file accessing, and all the necessary hardware interfacing logic [50]. A comparison of system requirements for the above mass storage devices is given in Table 4.

TABLE FOUR

Device Requirements

	Audio Cassette	Digital Cassette	Floppy Disk	Mini Floppy Disk
Average Access Time	15-23 min	4 min	1/3 sec	1/2 sec
Cost of kit for drive, interface & controller	under $200	under $600	$700-$1500	$600-$900
Interfacing Software Size (Bytes)	400	4K	5K	5K
Data Stored (Allowing for system overhead)	64K	300K	300K	64K
Number of Files	200 (approx)	unlimited	255	127
Transfer Rate	30 - 240	600	20K	10K

Ref (50)

C. HARDWARE PROBLEMS

The greatest hardware problem faced by personal computer users is the lack of adequate documentation, particularly in the area of kit construction. Many computer journals refer to the developing personal computer industry as a "garage shop phenomenon." Microcomputers can be manufactured by any company which can buy the basic chips and put them on a PC card and supply such software and service as their expertise allows. Among the problems faced by kit builders are the following: inoperability of the computer after assembly, inclusion of parts not shown on wiring diagrams or on parts lists, incorrect order of assembly of components necessitating unsoldering of previously assembled parts, and a lack of service from the vendor or slow service from the manufacturer in resolving these problems [51]. These problems can be minimized by the personal computer user either by the purchase of assembled components or the purchase of kits from the more firmly established companies.

Other items of concern include the cost of peripheral devices and their interfacing requirements. With market expansion and technological advances, the cost of peripherals should decrease. The personal computer purchaser must be aware of the bus structure of his intended purchase. Although the S-100 bus has been termed the industry standard, other bus structures do exist. For example, the computer products that Heath Company will begin selling in the fall of 1977 will employ a 50 pin bus, presumably to limit the user to purchases of Heath Company peripherals unless he is willing to accept the expense of interfacing logic for non-Heath Company peripherals [52].

V. MICROCOMPUTER SOFTWARE

In spite of their small size, microcomputers are still complicated devices and require extensive software support to be useful. This support can come from a variety of sources, including the microcomputer manufacturer, the microprocessor manufacturer, other microcomputer vendors and users, independent software distributors, and users groups and hobbyist clubs. Most vendors provide at least a minimal system of assembler and a primitive keyboard monitor and/or debug package since without them, a microcomputer is a rather expensive paperweight. A few companies provide true operating systems and even high level languages. This section describes the types of software support that are available for microcomputers.

A. ASSEMBLERS/EDITORS

Although it is possible to do programming in machine language (binary, octal, or hexadecimal) using a debug monitor, programs written in assembly language using combinations of letters and numbers (mnemonics) to represent instruction codes are easier for human interaction with the computer. Programs called assemblers translate assembly language programs into machine language for execution by the computer. Assemblers permit programmers to annotate their programs with comments and to explain and document the purpose and operation of the instruction.

Most microcomputer manufacturers produce an assembler to aid in program writing. Assembler programs are available as both resident and cross assembler programs. The availability of resident assemblers can significantly increase programming convenience. The limitation of resident assembler programs however is that significant expense is involved in providing a mass storage device to store this program. For example, the assembler program for a typical microcomputer, the SWTPC 6800, runs in 8K bytes of read/write memory but requires at least a 12K system to allow the user to assemble medium size application programs. The requirement for a mass storage device can be curtailed by the use of cross assemblers on a large-scale computer. This type of service, however, is generally unavailable to the personal computer enthusiast [53].

Assembly language programming can have the advantage of allowing a program to execute using fewer instructions than one written in a higher order language and compiled into machine instructions. This allows a faster execution time and requires less memory. The price paid for this possible advantage is the extra time required for the user to become proficient at assembly language [54].

Along with the assembler, a programmer requires an editor program to allow him to change his symbolic language and correct errors. With resident assemblers, this may be provided as part of the assembler or it may be a separate program with its own storage requirement.

B. LOADER/DEBUG PACKAGE

Once the program has been assembled, it is read into the microcomputer memory by a program known as a loader. Microcomputers such as the MITS Altair 680 and SWTPC 6800 which use the Motorola M6800 microprocessor maintain the loader program on ROM. ROM utilized in this manner provides a firmware function known as a monitor which enables microcomputers that use the M6800 microprocessor to operate with a nearly naked front panel. The SWTPC 6800 uses a standard monitor, known as the MIKBUG, developed by Motorola while the MITS Altair 680 uses a monitor designed exclusively for MITS by Micro-Soft. As a result, programs written for a MIKBUG oriented computer are not interchangeable with Micro-Soft oriented computers [53].

Computers, such as the MITS Altair 8800, which do not have a loader program present in the machine in ROM make use of a bootstrap loader. Such a program is usually on tape and requires several instructions to be keyed in by hand, via toggle switches on the front panel, to initialize and direct the reading of the loader. The bootstrap loads itself and is then capable of loading an assembled program [55].

The inclusion of a monitor in ROM makes the development and running of programs easier and also permits using the read/write memory more effectively since none of it has to be taken up with storing monitor-type subroutines.

Many of the microcomputer manufacturers provide their machines with a debug program as part of the monitor which allows the programmer to examine and modify the contents of

registers and memory. The debug function also allows the insertion of "breakpoints" in the program. In this way the programmer can walk through the execution of the program and isolate bugs [56].

C. COMPILERS

Compilers function much like assemblers and they are necessary for high level languages. With high level languages, the programmer specifies a number of general commands (source code) which are translated by the compiler software into the specific instructions (machine code) necessary for the microcomputer to perform the task indicated. Compilers make programming easier and faster because fewer statements are required to implement an algorithm, however this is balanced by a slower speed of program execution, a decrease in efficiency of memory utilization, and a requirement for a significant amount of off-line storage. Another negative feature is the non-availability of compilers that operate on microcomputers although compilers for this purpose are under development. At present, cross compilation on large computers is used to compile programs written in high order languages for use on microcomputers [57].

D. INTERPRETERS

Assemblers and compilers can be classified as translators which accept source language and change it into an object code which can then be loaded into the computer for execution. In place of a compiler, an interpreter can be used to execute high order language programs. Unlike

translators, interpreters execute the source language directly without the intermediate process of translation to an object code. Interpreters have the advantage that a small amount of storage is required for this language processor to work while the efficiency of the programmer is high because of the use of high level language. Usually, the interpreter provides direct and indirect modes of program execution. The direct mode enables the programmer to execute statements as they are entered allowing interaction with the computer for correction of syntax errors prior to resuming execution. In the indirect mode, commands are stored for later execution [58].

When compared to compilation, interpreters have the disadvantage that more time per statement is required since statements are considered one at a time. Because statements are not considered as a group, interpreters are unable to resolve syntactical inconsistencies that compilation would disclose.

Most of the high level language processors used in microcomputer systems are pure source-code interpreters.

E. HIGH LEVEL LANGUAGE

The availability of high level languages for microcomputers through the use of interpreters has increased the attractiveness of personal computer systems. High level languages provide a powerful and fundamental form of software for any system by allowing the description and solution of problems in a form that is easy for the user. While high level languages are not as efficient as assembly languages in terms of memory utilization and speed of program execution, they have the advantage of being easy to

learn and easy to use.

The most widely used high level language in personal computer systems is BASIC, which stands for Beginners' All-purpose Symbolic Instruction Code. BASIC language is offered by most microcomputer manufacturers because it is perhaps the easiest language to learn and because it can be used for numerous applications. Literally thousands of BASIC programs have been written and are in the public domain. These programs include accounting programs, business programs, scientific programs, educational programs, game programs, engineering programs, and much more. BASIC is an interactive language allowing the user to receive immediate feedback from the interpreter as BASIC statements are entered. In this manner syntactical and logical errors can be identified and corrected. This assists the programmer in the writing of long complicated programs.

Many suppliers offer three versions of BASIC [59]: 4K BASIC - designed to run on as little as 4K of read/write memory, 8K BASIC, or EXTENDED BASIC (12K). The different versions are suited to different applications.

1. 4K BASIC

4K BASIC is a small version of the versatile BASIC language designed for applications requiring just mathematical manipulation without extensive processing of text. It includeds 16 statements in addition to 4 commands and 6 functions. 4K BASIC is designed to run in a system having a minimum of 4K of read/write memory. In a 4K system, 4K BASIC as offered by MITS for their Altair products leaves approximately 750 bytes of memory for storage of the user's high level language program.

2. 8K BASIC

The Altair 8K BASIC interpreter requires 5.9K of read/write memory. If the system contains 8K of RAM, 2.1K net bytes of RAM are left for the user's programming. 8K BASIC has the same capabilities as 4K BASIC but it includes 4 additional statements, 1 additional command, and 8 additional functions. Other features include multidimensioned string and numeric arrays, the ability to read or write a byte from any I/O port or memory location, the ability to interrupt program execution and then continue after examination of values, and multi-line, multi-variable user functions. With 8K BASIC, print statements provide fully formatted output for multiple devices such as CRT screen, teletype, or line printer. Multi-dimensional arrays permit fast processing of data that can be organized graphically or in tabular form. 8K BASIC is particularly useful for applications requiring lists of names or numbers such as accounting programs, inventory programs, and mailing lists.

3. EXTENDED BASIC

Many firms also offer versions of BASIC they call EXTENDED BASIC which is similar to 8K BASIC with the addition of double precision arithmetic, the statement PRINT USING which provides complete control over output format, as well as other features. The Altair version of EXTENDED BASIC requires 10.2K bytes of read/write memory, leaving 1.8K bytes of a 12K RAM system available for the user's high level language program.

Some personal computer systems offer an EXTENDED DISK BASIC which allows users to save and recall programs and data files from floppy disk drives. Random access as well as sequential file access capability is provided. EXTENDED DISK BASIC systems generally include all features of EXTENDED BASIC and require 16K bytes of read/write memory.

The above software programs are available on several mediums: paper tape, magnetic cassette tape, floppy discs, and PROM devices. Software implemented on PROM devices offers the user the greatest convenience in that the program need not be loaded into the system each time the system is powered up.

F. OPERATING SYSTEMS

Operating systems for low-end personal microcomputers are rather primitive unless considerable memory is available. Cassette operating systems and disk operating systems are available for use on microcomputers which have been equiped with cassette tape recorders or floppy disk drives and provide file management capabilities for these peripherals. However, the extent of operating system capability is usually limited to the previously mentioned keyboard monitors which rarely have any mass storage or file handling capability. Monitors generally provide only an ability to examine and load registers under memory control and to transfer control to a specified location [58].

G. SOFTWARE PROBLEMS

1. Machine Independence

Software presents a major problem that will have to be overcome before the industry can make a successful transition from the hobby market to the mass market. Not only is software expensive to develop, but there is no driving force to standardize software systems. For example, software interpreter programs written for a system based on 8080 hardware will not run on a 6800 hardware system. Even for microcomputers based on the same microprocessor, software interpreter programs written for one manufacturer's microcomputer will often fail to operate on an alternate vendor's product. These problems can be attributed to assumptions made by the software developer regarding location or transparancy of a monitor, use of a monitor for input/output operations, direct memory access or interrupt protocols, or use of an input/output port or address for a particular purpose [60].

Similarly, application programs written in high level languages such as BASIC often cannot be freely interchanged between systems. Each manufacturer offers his own particular version of the language which may contain control statements, commands, or functions that a second vendor does not include.

For the hobby computer user, the availability of a fairly wide range of software can be ensured by staying within the mainstream of microprocessors and microcomputers marketed for personal computing;e.g., the 8080 and 6800

microprocessors and IMSAI and MITS microcomputers. Programs for specific applications such as business use (accounting, bookkeeping, inventory, and payroll programs), educational use (math, programmed teaching instruction, and engineering programs), hobby use (games) and research are available in bound publications and are written in BASIC which is compatible for execution on the most widely used personal computers.

Purchase of a personal computer often entitles the user to membership in hobbyist clubs which serve as a forum for interchange of information regarding means of resolving hardware and software problems that arise in that particular system. Many of these clubs also maintain software libraries although they may vary in their degree of reliability. Some manufacturers are also forming users groups for their products and they solicit applications programs written by users which will be made available to other user group members.

2. <u>Distribution</u>

The distribution of software also presents problems. At present several mediums are used to distribute software: paper tape, magnetic cassette tape, floppy disks, and PROM devices. Some of these mediums are both fragile and costly. A variety of encoding techniques exist for cassette tape and floppy discs. This presents a requirement for compatible hardware among users desiring to exchange programs on these mediums.

In a recent article by Jim Warren, editor of <u>Dr. Dobb's Journal</u>, a hobbyist publication concerned primarily with the design and implementation of software, several solutions to the problem of machine independent software

were addressed. "Publication and distribution of source code can greatly simplify the problem of customizing a program for a given hardware configuration. Transparent monitors are another obvious aid. Assemblers and loaders that can produce and process relocatable and segmented code will reduce the problem. Careful modularization of the software - with particular attention being given to isolation of I/O and hardware dependent code - will help [60]." Complete documentation of software is another obvious aid.

Efforts at standardization of data encoding techniques have been made. The "Kansas City" standard is an example of this. The problem of the multiplicity of standards used on cassette tape has been circumvented by one manufacturer, Tarbell Electronics, by producing an interface that will read any of three recording standards.

3. Cost

The cost of software varies greatly. BASIC interpreter programs, assembler/editor programs, monitor programs, and disc/cassette operating systems are supplied by some microcomputer manufacturers with the cost included in the hardware for purchasers of complete microcomputer systems, while other vendors and independent software distributors charge according to the convenience afforded by the medium. Software programs implemented on PROM devices are generally the most expensive with costs in the range of $50 for each 1K PROM. Table 5 provides a comparison of the above software costs.

TABLE FIVE, Personal Computer Software

Distributor	Description	Paper Tape	Cassette	EPROM(1)	Diskette	Minimum Memory Req'd(3)
The Digital Group	Assembler		$15			12K Bytes
	Text-Editor		7.50			
(Z-80 or 8080)	Maxi BASIC		15			8K
IMSAI 8080(2)	Assembler/Editor	$14	20	$100	-	8K
	4K BASIC	14	30	100	-	4K
	8K BASIC	28	40	200	-	8K
	Disk OS	-	-	-	50	16K
	Tape Cassette OS	-	20	100	-	4K
	Bootstrap Loader	-	-	15	-	512 Bytes
		List	Qualified(2)			
MITS ALTAIR 8080	4K BASIC	$150	$60			3.2K
	8K BASIC	200	75			6K
	Extended BASIC	350	150			10.2K
	Disk OS	500	200			16K
ALTAIR 680	8K BASIC	200	no charge			6.8K
	Assembler/Editor	75	no charge			8K

Notes (1) EPROM programming charge, cost of EPROM is additional

(2) Price with purchase of qualifying system

(3) Working storage is additional

The high cost of some software programs subjects them to extensive unauthorized duplication and distribution among users without compensation to the developers. Since the hobby market offers a very narrow profit margin, software piracy curtails any incentives for software development by independent distributors.

Various publications dedicated to the small scale computer system users have been providing a solution to the problems of software distribution and cost. The May 1977 issue of <u>Interface</u> initiated a program of distribution of software by means of audio record inserts which <u>Interface</u> refers to as Floppy - ROMs. The first of these records provided a 4K BASIC interpreter program for 6800 series microprocessor based systems with MIKBUG loaders. Patching instructions and separate loader programs are provided for systems without the MIKBUG loader. <u>Interface</u> plans to distribute additional Floppy - ROMs for 8080, Z-80, and 6502 CPU systems [61]. All that is required to load the Floppy-ROM is a monoaural 33RPM turntable and a modulator/demodulator capability to detect "Kansas City" standard frequency shift keyed audio signals and output digital data. This detector capability is provided by standard cassette tape interfaces.

Other journals distribute software in machine readable print format for users with optical bar code reader capabilities [62].

As the personal computer market expands, high volume distribution of software will possibly allow software developers to remain competitive with a small profit margin. By making software available at prices that are comparable to the costs of unauthorized copying of the software, unauthorized copying will be discouraged.

VI. SUMMARY

Low cost microprocessor-based computers are being used in ever increasing numbers. Numerous small companies pursuing the personal computer market offer a variety of products with wide ranging capabilities. The potential personal computer buyer should be aware of the capabilities and limitations of the competing products, particularly in the area of computer mainframes. The available microcomputer mainframe assemblies include different amounts of memory and peripheral device interface, power supply and system expansion capabilities which have impact on future costs to the buyer.

The cost of personal computer mainframes is quickly overshadowed by the cost of providing peripheral devices to allow human interaction with the computer, memory to support software, and software to provide interfacing capabilities with peripheral devices. Software and hardware support and availability varies widely between different systems and is often a function of the microprocessor used in the system. Many personal computer manufacturers are avoiding potential hardware servicing problems by turning away from kit production and concentrating on the production of assembled components. The gradual development of software as the market matures is diminishing software availability problems. Compatibility of hardware and software between systems based on different microprocessors remains an important aspect to be considered by the personal computer buyer.

At present more than one-third of computer owning hobbyists have invested over $2,000 in their systems [30]. Many have invested twice that amount to achieve systems capable of any practical applications. Prior to the emergence of a true mass consumer market, the price of personal computers will have to decrease substantially. Advances in technology and the influence of the efficiencies of mass production will eventually provide lower cost computer components opening personal computing to the true mass market.

The demand for low cost computing systems by small businesses and educational institutions has supplemented the demand of hobbyists. Competition to meet these demands is increasing. 1977 is likely to go on record as the year when the personal computer began changing from a small, but surging hobby kit market pursued by dozens of small companies to a huge mass market dominated by the nation's largest electronic equipment manufacturers and retailers. The small hobby computer manufacturers, in many cases undercapitalized and inexperienced, have sparked the interest of every consumer electronics manufacturer and mass retailer. Large companies are beginning to enter the personal computer field. During early 1977, Pertec Computer Corp. acquired MITS, the leading home computer maker: Computer Machinery Corp., with an established sales network: and iCom, a producer of microcomputer peripheral hardware; to supplement its existing business of making memories and display terminals for minicomputers. By this merger, Pertec can take advantage of vertical integration in selling complete microcomputer systems, provide access to more service outlets and utilize the stronger financial backing and production skills of a larger company. Other keys moves in the direction of mass marketing include the entrance of retailers such as Heath Company and Radio Shack who will

sell their own line of home computer products. Commodore Business Machines has announced plans to mass-merchandise, through television advertising, a self-contained turnkey microcomputer, called PET, which will sell at retail for $495. It will include a TV monitor for graphics and text display, a typewriter-like keyboard for input, and cassette tape memcry.

The average consumer will be partial to low cost (under $500), readily available computers that are easy to operate. While the entrance of large industry into the personal computer market may cause many of the small hobby computer manufacturers to go out of business, as with the early entrants in the hand calculator market, their ability to provide lower cost computers will mark a step in the direction of personal computers for the masses.

LIST OF REFERENCES

1. Twitty, R., "The LSI Microprocessor", Mini-Micro Systems, v. 9, p. 76,77, May 1976.

2. Vacroux, A. G., "Microcomputers", Scientific American, v. 232, p. 32, May 1975.

3. Intel Corporation, Intel 8080 Microputer Systems User's Manual, p. ii, September 1975.

4. Roberts, H. E. and Yates, W., "ALTAIR 8800", Popular Electronics, v. 9, p. 33, January 1975.

5. "The Coming Boom In Home Computers", Business Week, no. 2479, pp. 50E-50G, May 1977.

6. Mennie, D., "Everybody's Doing It ('Computing' at Home)", IEEE Spectrum, v. 14, p. 29,30, May 1977.

7. Osborne, A., An Introduction to Microcomputers, Vol. 1, p. 1-3,1-4, Osborne and Associates, Inc., 1976.

8. Vacroux, A. G., "Microcomputers", Scientific American, v. 232, p. 33, May 1975.

9. Bylinsky, G., "Here Comes The Second Computer Revolution", Fortune, v. XCII, p. 136,137, November 1975.

10. Torrero, E. A., "Choosing a Microprocessor", Microprocessor Basics, ed. Elphick, M. S., pp. 8-12, Hayden, 1977.

11. Vacroux, A. G., "Microcomputers", Scientific American, v. 232, p. 34, 36-38, May 1975.

12. McPhillips, A. S., "Inside Microprocessors", Modern Data, v. 8, p. 40, January 1975.

13. Pedersen, R. A., "Integrated Injection Logic A Bipolar LSI Technique", IEEE Computer, v. 9, p. 24-29, February 1976.

14. Stark, P. A., " Everything About Semiconductor Memory", Kilobaud, v. 4, p. 96-101, April 1977.

15. Gilder, J. H., " All About Microcomputers", Computer Decisions, v. 7, p. 44-49, December 1975.

16. Osborne, A., An Introduction to Microcomputers, Vol. 2, p. 1-1, Osborne and Associates, Inc., 1976.

17. Hilburn, J. L. and Julich, P. M., Microcomputers/ Microprocessors, p. 197-234, Prentice-Hall, Inc., 1976.

18. Ogdin, J. L., "Microprocessors: The Inevitable Technology", Modern Data, v. 8, p. 42-47, January 1975.

19. Bowers, D. M., " Microprocessor Scorecard", Mini-Micro Systems, v. 9, p. 42-48, July 1976.

20. Intel Corporation, Intel 8080 Microcomputer Systems User's Manual , pp. 3-1 - 3-10, September 1975.

21. Nichols, A. J. and McKenzie, K., "Build a Compact Microcomputer with the 8080," Microprocessor Basics, ed. Elphick, M. S., pp. 59-67, Hayden, 1977.

22. Osborne, A., An Introduction to Microcomputers, Vol. 2, p. 5-1 - 5-6, Osborne and Associates, Inc., 1976.

23. Salisbury, A. B., "Eeny, Meeny, Micro and More", Creative Computing, v. 2, p. 87,88, May/June 1977.

24. Hashizume, B., "Microprocessor Update: Zilog Z-80", Byte, v. 1, p. 34-38, August 1976.

25. Motorola Semiconductor Products Inc., _M6800 Microprocessor Applications Manual_, pp. 1-1 - 1-20, 1975.

26. Mazur, T., "Assemble a Complete Microcomputer with the 6800", _Microprocessor Basics_, ed. Elphick, M. S., pp. 89-100, Hayden, 1977.

27. Lynch, F., "Keep the PACE Up and Running", _Microprocessor Basics_, ed. Elphick, M. S., pp. 139-145, Hayden, 1977.

28. Grieshaber, B., "Consider the 6100 for CMOS Systems", _Microprocessor Basics_, ed. Elphick, M. S., pp. 208-215, Hayden, 1977.

29. Intel Corporation, _Intel 8080 Microcomputer Systems User's Manual_ , p. iv, September 1975.

30. Kaplan, A. R., "Home Computers Versus Hobby Computers", _Datamation_, v. 23, p. 72-75, July 1977.

31. Yasaki, E. K., "Microcomputers: For Fun and Profit?", _Datamation_, v. 23, p. 66-77, July 1977.

32. Garland, H., "Design Innovations in Personal Computers", _IEEE Computer_, v. 10, p. 24-27, March 1977.

33. Hilburn, J. L. and Julich, P. M., _Microcomputers/ Microprocessors_, pp. 79-86, Prentice-Hall, Inc., 1976.

34. Gray, S. B., "Computer Bits", _Popular Electronics_, v. 11, p. 95-96, April 1977.

35. Vacroux, A. G., "Microcomputers", _Scientific American_, v. 232, p. 37,38, May 1975.

36. Edelson, R., "Card of the Month, Cromenco BYTESAVER", _Interface Age_, v. 2, p. 64-73, January 1977.

37. Fowler, J. C., "Those Exciting Memory Chips: RAMs, ROMs, PROMs," Hobby Computers Are Here , ed. Green, W., pp. 36-43, 73, Inc., 1976.

38. Derman, S., "Benchmark Testing of Microprocessors", Microprocessor Basics, ed. Elphick, M. S., pp. 47-49, Hayden, 1977.

39. Leventhal, L. A., "Microprogramming", Kilobaud, v. 1, p. 120-123, April 1977.

40. Hilburn, J. L. and Julich, P. M., Microcomputers/ Microprocessors, p. 150-153, Prentice-Hall, Inc., 1976.

41. Hilburn, J. L. and Julich, P. M., Microcomputers/ Microprocessors, p.112, Prentice-Hall, Inc., 1976.

42. Bowers, D. M., "Systems-On-a-Chip", Mini-Micro Sytems, v. 9, p. 79, May 1976.

43. Ahl, d., "Hints on Buying a Teletype", Creative Computing, v. 2, p. 23, November/December 1976.

44. Hawkins, W. J., "Your Own Home Computer", Popular Science, v. 210, p. 102-105, May 1977.

45. Flystra, D., "Interfacing the IBM Selectric Keyboard Printer", Byte, v. 2, p. 46-52, June 1977.

46. Kay, G., "A Review of the SWTPC PR-40 Alphanumeric Printer", Byte, v. 2, p. 18-24, March 1977.

47. Warren, J., "Personal and Hobby Computing: An Overview", IEEE Computer, v. 10, p. 15, March 1977.

48. Hutton, L. I., "Build This Exciting New TVT", Hobby Computers Are Here, ed. Green, W., pp. 52-58, 73, Inc., 1977.

49. Tarbell, D., "Meet the Tarbell/KC Interface", Kilobaud, v. 1, p. 44-46, April 1977.

50. Allen, P., "Software Column", Personal Computing, v. 1, p. 63,64, March/April 1977.

51. Himmerfarb, M., "The Makings of a Mini", Digital Design, v. 5, p. 80, August 1975.

52. Gray, S. B., "Heath: Two Computers and Two Peripherals for Openers", Creative Computing, v. 3, p. 36,37, July/August 1977.

53. Teener, M. D., "Minicomputers and Microcomputers", Mini-Micro Systems, v. 9, p. 46,47, June 1976.

54. Salisbury, A. B., "Beyond Basic", Creative Computing, v. 2, p. 29, November/December 1976.

55. Ogdin, J., "Software Tools", Popular Electronics, v. 9, p. 102, November 1975.

56. Wyland, D. C., "Software Support for Microprocessors", Microprocessor Basics, ed. Elphick, M. S., p. 20, Hayden, 1977.

57. Cassell, D. A., "Microcomputer Programming", Modern Data, v. 8, p. 51, January 1975.

58. Salisbury, A. B., "Beyond Basic", Creative Computing, v. 2, p. 30,31, November/December 1976.

59. Sippl, C. J., Microcomputer Dictionary and Guide, p. 528-534, Matrix Pub. Inc., 1976.

60. Warren, J., "Personal and Hobby Computing: An Overview", IEEE Computer, v. 10, p. 17,18, March 1977.

61. Jones, R. S., "Platter Basic", Interface Age, v. 2, p. 28-33, May 1977.

62. Banks, W., "Samples of Machine Readabe Printed Software", Byte, v. 1, p. 12-20, December 1976.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Arlington, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 54 Department of Administrative Sciences Naval Postgraduate School Monterey California 93940	2
4.	Professor N. F. Schneidewind, Code 54Ss Department of Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
5.	LTCCL Ronald J. Roland, Code 52Rl Department of Computer Science Naval Postgraduate School Monterey, California 93940	2
6.	Commandant, G-PTE-1/72 United States Coast Guard Washington, D. C. 20590	2
7.	LT H. Paul Libuda, USCG 12850 Oakfield Way Poway, California 92064	1

8. CDR John T. Vinson, Code 62Vn 1
Department of Electrical Engineering
Naval Postgraduate School
Monterey California 93940